III-Nitride Materials and Devices for Power Electronics

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GaN and related materials and devices for power electronic applications are expected to compete with and, possibly, outperform silicon carbide. However, novel approaches to III-N material and device development are required for this materials system being able to achieve its full potential.

GaN, AlGaN, AlInGaN and other III-Nitride compound materials offer a very high breakdown field. . This property alone makes them extremely attractive for power converters and other power electronics systems. AlGaN/GaN heterostructure field effect transistors (HFETs) have a number of additional advantages critically important for power electronics. These are very high electron density and mobility in the device channel, leading to record low device on-resistance, high temperature stability allowing device operation at temperatures up to 350 ^{o}C or even higher, chemical inertness, low gate capacitance enabling high switching speed and low switching loss.

Most of the early efforts on GaN HFET development have been focused on microwave power amplifiers. Record high microwave power densities of 10 – 30 W/mm of device periphery for III HFETs exceeded those achievable using Si or GaAs technologies for up to two orders of magnitude.

The first high power GaN devices have been successfully demonstrated since late 90s [1,2,3,4]. However, after more than ten years of extensive development, the commercialization of GaN devices for power electronic applications is still in its very early stages. The gap between the performance expected based on nitride materials properties and obtained results remains large. Even more significantly, reliability problems hampered the deployment of this technology. Unlike most of other semiconductor materials, III-Nitride materials are mostly grown over foreign substrates: sapphire, SiC or Si. This is due to the lack of native GaN crystals. Heterogrowth leads to very high dislocation densities, orders of magnitude higher than those in Si and other “classical” semiconductor materials. A high dislocation density and other defects lead to severe reliability issues.

Another important issue affecting the III-Nitride device performance is related to the heterostructure transistor design. High electron density and mobility are achieved at the AlGaN/GaN or AlInN/GaN heterointerface. This design calls for lateral structures having the device active region located within just 10 – 20 nm from the surface. Surface related effects lead to a deterioration of the device performance. The most important of them are (i) much lower achieved breakdown voltages than those expected from material properties, (ii) significant trapping effects and as a results higher on-resistance in pulse mode compared to DC values and (iii) poor parameter stability and reliability

The efforts that III-Nitride community is currently pursuing are focused on both material quality improvement and novel device designs to eliminate or at least alleviate the existing issues.

Material research efforts include the novel epitaxial techniques, such as Migration Enhanced Metal Organic Chemical Vapor Deposition (MEMOCVD®), techniques for reducing the defect density in epitaxially grown III-Nitride layers, substrate quality and orientation management, substrate patterning and search for alternative substrate materials, including significant efforts to obtaining high quality bulk GaN, AlN, and AlGaN crystals.

Material research also includes studies of III-Nitride heterostructures beyond commonly used AlGaN/GaN. As an example, AlGaN/AlGaN and AlGaN/GaN/AlGaN heterostructures promise for significantly higher breakdown voltage compared to AlGaN/GaN.

Device development include a large spectrum of multifaceted efforts on eliminating electron trapping, surface related premature breakdown, increasing device reliability, moving towards vertical geometry power devices, more similar to those traditionally used in Si power technology.

In this talk, we will review the most important efforts and achievements in the areas of material growth, novel power device concepts, designs, modeling and simulations.

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